arXiv:hep-ph/0206242 v2 12 Sep 2002

DESY 02-089

Implications of $B \to \rho\gamma$ measurements in the Standard Model and Supersymmetric Theories

A. Ali[1] and E. Lunghi[2]

Deutsches Elektronen Synchrotron, DESY,
Notkestrasse 85, D-22607 Hamburg, Germany

Abstract

We study the implications of the recently improved upper limits on the branching ratios for the decays $B \to \rho\gamma$, expressed as $R(\rho\gamma/K^*\gamma) \equiv \mathcal{B}(B \to \rho\gamma)/\mathcal{B}(B \to K^*\gamma) < 0.047$. We work out the constraints that the current bound on $R(\rho\gamma/K^*\gamma)$ implies on the parameters of the quark mixing matrix in the standard model (SM). Using the present profile of the unitarity triangle, we predict this ratio to be $R(\rho\gamma/K^*\gamma) = 0.023 \pm 0.012$. We also work out the correlations involving $R(\rho\gamma/K^*\gamma)$, the isospin-violating ratio $\Delta(\rho\gamma)$, and the direct CP-violating asymmetry $A_{\rm CP}(\rho\gamma)$ in $B \to \rho\gamma$ decays in the SM, in the minimal supersymmetric extension of the SM (MSSM), and in an extension of the MSSM involving an additional flavor-changing structure in $b \to d$ transitions.

[1]E-mail address: ali@mail.desy.de
[2]E-mail address: lunghi@mail.desy.de

1 Introduction

Recently, the BABAR collaboration has reported a significant improvement on the upper limits of the branching ratios for the decays $B^0(\bar{B}^0) \to \rho^0\gamma$ and $B^\pm \to \rho^\pm\gamma$. Averaged over the charge conjugated modes, the current 90% C.L. upper limits are [1]:

$$\mathcal{B}(B^0 \to \rho^0\gamma) < 1.4 \times 10^{-6} , \quad (1)$$
$$\mathcal{B}(B^\pm \to \rho^\pm\gamma) < 2.3 \times 10^{-6} , \quad (2)$$
$$\mathcal{B}(B^0 \to \omega\gamma) < 1.2 \times 10^{-6} . \quad (3)$$

They have been combined, using isospin weights for $B \to \rho\gamma$ decays and assuming $\mathcal{B}(B^0 \to \omega\gamma) = \mathcal{B}(B^0 \to \rho^0\gamma)$, to yield the improved upper limit

$$\mathcal{B}(B \to \rho\gamma) < 1.9 \times 10^{-6} . \quad (4)$$

The current measurements of the branching ratios for $B \to K^*\gamma$ decays by BABAR [2],

$$\mathcal{B}(B^0 \to K^{*0}\gamma) = (4.23 \pm 0.40 \pm 0.22) \times 10^{-5} , \quad (5)$$
$$\mathcal{B}(B^+ \to K^{*+}\gamma) = (3.83 \pm 0.62 \pm 0.22) \times 10^{-5} , \quad (6)$$

are then used to set a 90% C.L. upper limit on the ratio of the branching ratios [1]

$$R(\rho\gamma/K^*\gamma) \equiv \frac{\mathcal{B}(B \to \rho\gamma)}{\mathcal{B}(B \to K^*\gamma)} < 0.047 . \quad (7)$$

This bound is typically a factor 2 away from the SM estimates [3], which we quantify more precisely in this letter. In beyond-the-SM scenarios, this bound provides a highly significant constraint on the relative strengths of the $b \to d\gamma$ and $b \to s\gamma$ transitions.

The impact of the measurement of $R(\rho\gamma/K^*\gamma)$ on the parameters of the quark mixing matrix (henceforth called the Cabibbo-Kobayashi-Maskawa CKM matrix) has been long anticipated (see, for example, [4]). This quantity measures essentially the CKM matrix element ratio $|V_{td}|^2/|V_{ts}|^2$ in the SM. However, one expects significant long-distance contributions in $R(\rho\gamma/K^*\gamma)$ entering in the decay $B \to \rho\gamma$. They are dominated by the annihilation diagrams $b\bar{u} \to d\bar{u}\gamma$ in the decays $B^- \to \rho^-\gamma$ [5, 6, 7, 8], which depend on the CKM matrix elements $V_{ub}V_{ud}^*$. The corresponding annihilation contribution in the decays $B^0 \to \rho^0\gamma$ (and its charge conjugate) is parametrically suppressed due to the electric charge of the spectator quark in B^0 and the unfavorable color factors. QCD corrections to the decay widths for $B \to \rho\gamma$ also introduce a dependence on $V_{ub}V_{ud}^*$ in both the charged and neutral B-meson decays. As the relevant CKM matrix element ratio $\lambda_u \equiv V_{ub}V_{ud}^*/V_{tb}V_{td}^*$ is of $O(1)$, these modifications are important and have to be taken into account in the analysis of $R(\rho\gamma/K^*\gamma)$ and other observables in $B \to \rho\gamma$ decays.

Recently, the $O(\alpha_s)$ corrections in the decay widths for $B \to V\gamma$ ($V = K^*, \rho$) have been calculated in the context of a QCD factorization framework [9], taking into account the explicit $O(\alpha_s)$ and $1/M_B$ corrections to the penguin amplitudes [3, 10, 11]. Using the theoretical results at hand, we analyze the impact of the current upper limit $R(\rho\gamma/K^*\gamma) < 0.047$

$\zeta = 0.76 \pm 0.10$ $A^{(1)K^*} = -0.113 - i0.043$ $A^u = -0.0181 + i0.0211$	$L_R^u = -0.095 \pm 0.022$ $A^{(1)t} = -0.114 - i0.045$
$\eta_{tt} = 0.57$ $\eta_{tc} = 0.47 \pm 0.04$ $\eta_B = 0.55$ $\xi_s = 1.18 \pm 0.04^{+0.12}_{-0}$	$\eta_{cc} = 1.38 \pm 0.53$ $\hat{B}_K = 0.86 \pm 0.15$ $f_{B_d}\sqrt{\hat{B}_{B_d}} = 235 \pm 33^{+0}_{-24}$ MeV
$\lambda = 0.221 \pm 0.002$ $\epsilon_K = (2.271 \pm 0.017)\ 10^{-3}$ $a_{\psi K_s} = 0.734 \pm 0.054$	$\lvert V_{ub}/V_{cb}\rvert = 0.097 \pm 0.010$ $\Delta M_{B_d} = 0.503 \pm 0.006$ ps^{-1} $\Delta M_{B_s} \geq 14.4$ ps^{-1} (95% C.L.)

Table 1: *Theoretical parameters and measurements used in $B \to \rho\gamma$ observables and in the CKM unitarity fits.*

in the context of the SM, where it yields constraints on the CKM parameters $\bar{\rho}$ and $\bar{\eta}$ [3], and in some popular extensions of the SM, such as the minimal flavor violating minimal supersymmetric standard model (MFV-MSSM) [12], and in an Extended–MFV-MSSM scenario (EMFV) [13], having a non-CKM flavor-changing structure involving the $b \to d$ transition. We also present the correlations involving $R(\rho\gamma/K^*\gamma)$, the isospin-violating ratio $\Delta(\rho\gamma)$, and the direct CP-violating asymmetry $A_{\rm CP}(\rho\gamma)$ in $B \to \rho\gamma$ decays, in the three models just mentioned. Precise measurements of these correlations would provide a strong discrimination among the competing models.

2 Observables

The effective Hamiltonian for the radiative decays $B \to \rho\gamma$ (equivalently $b \to d\gamma$ decay) can be seen for the SM in [3]. We shall invoke this effective Hamiltonian also for the MFV-MSSM and the EMFV cases, which differ from the SM in the Wilson coefficients (WC's), in particular in the effective WC's for the magnetic moment operator, C_7^s (for $b \to s\gamma$) and C_7^d (for $b \to d\gamma$). While this is certainly not the most general operator basis, it is a sufficient basis to illustrate the beyond-the-SM effects that may arise in these decays. Restricting ourselves to this basis, we first present the $O(\alpha_s)$-corrected expressions for the observables in the $B \to \rho\gamma$ decays, worked out in the SM in [3, 10], but now generalized to the case of complex Wilson coefficients.

Here and in the following we will always consider quantities averaged over the charge conjugated modes (with the obvious exception of the CP asymmetries). Starting from the decay widths $\Gamma(B^+ \to V^+\gamma)$, $\Gamma(B^- \to V^-\gamma)$, $\Gamma(B^0 \to V^0\gamma)$ and $\Gamma(\bar{B}^0 \to \bar{V}^0\gamma)$ (with $V = \rho,\ K^*$), we construct

$$\Gamma^{\pm}(B \to V\gamma) = \frac{\Gamma(B^+ \to V^+\gamma) + \Gamma(B^- \to V^-\gamma)}{2}\,, \tag{8}$$

$$\Gamma^0(B \to V\gamma) = \frac{\Gamma(B^0 \to V^0\gamma) + \Gamma(\bar{B}^0 \to \bar{V}^0\gamma)}{2} \,. \tag{9}$$

We will define the various observables in terms of these quantities. Note that, up to the NLO approximation, this procedure is equivalent to defining two distinct observables for the charge conjugate modes and *then* performing the average. It is preferable to use the above definitions since they involve quantities (the CP averaged decay widths) that are much easier to measure than the widths of the individual channels, which would require tagging the B-meson.

The expression for the ratios $R(\rho\gamma/K^*\gamma)$ is [3]

$$R^{\pm}(\rho\gamma/K^{\gamma}) = \left|\frac{V_{td}}{V_{ts}}\right|^2 \frac{(M_B^2 - M_\rho^2)^3}{(M_B^2 - M_{K^*}^2)^3}\zeta^2(1 + \Delta R^{\pm}) \,, \tag{10}$$

$$R^{0}(\rho\gamma/K^{*}\gamma) = \frac{1}{2}\left|\frac{V_{td}}{V_{ts}}\right|^2 \frac{(M_B^2 - M_\rho^2)^3}{(M_B^2 - M_{K^*}^2)^3}\zeta^2(1 + \Delta R^{0}) \,, \tag{11}$$

where $\zeta = \xi_\perp^\rho(0)/\xi_\perp^{K^*}(0)$, with $\xi_\perp^\rho(0)(\xi_\perp^{K^*}(0))$ being the form factors (at $q^2 = 0$) in the effective heavy quark theory for the decays $B \to \rho(K^*)\gamma$. Noting that in the SU(3) limit one has $\zeta = 1$, some representative estimates of the SU(3)-breaking and the resulting values of ζ are: $\zeta = 0.76 \pm 0.06$ from the light-cone QCD sum rules [5]; a theoretically improved estimate in the same approach yields [14]: $\zeta = 0.75 \pm 0.07$; $\zeta = 0.88 \pm 0.02$ using hybrid QCD sum rules [15], and $\zeta = 0.69 \pm 10\%$ in the quark model [16]. Except for the hybrid QCD sum rules, all other approaches yield a significant SU(3)-breaking in the magnetic moment form factors. In the light-cone QCD sum rule approach, this is anticipated due to the appreciable differences in the wave functions of the K^* and ρ-mesons. To reflect the current dispersion in the theoretical estimates of ζ, we take its value as $\zeta = 0.76 \pm 0.10$, given in Table 1. We stress that the error (± 0.10) is not on $\zeta = 0.76$, but rather on the deviation of ζ from its SU(3) limit, i.e., $1 - \zeta = 0.24$, and amounts to an error of $\pm 42\%$ on the SU(3)-breaking in the ratio of form factors in radiative decays. As this is the dominant theoretical error on the ratios $R^{\pm}(\rho\gamma/K^{\gamma})$ and $R^{0}(\rho\gamma/K^{*}\gamma)$, it is imperative to reduce it. A lattice-QCD based estimate of the form factors, and hence ζ, is highly desirable.

The quantity $(1 + \Delta R)$ entails the explicit $O(\alpha_s)$ corrections, encoded through the functions $A_{\rm R}^{(1)K^*}$, $A_{\rm R}^{(1)t}$ and $A_{\rm R}^{u}$, and the long-distance contribution $L_{\rm R}^{u}$. For the decays $B^{\pm} \to \rho^{\pm}\gamma$ and $B^{\pm} \to K^{*\pm}\gamma$, this can be written after charge conjugated averaging as

$$1 + \Delta R^{\pm} = \left|\frac{C_7^d + \lambda_u L_R^u}{C_7^s}\right|^2 \left(1 - 2A_R^{(1)K^*}\frac{\mathrm{Re}\, C_7^s}{|C_7^s|^2}\right) + \frac{2\ \mathrm{Re}\left[(C_7^d + \lambda_u L_R^u)(A_R^{(1)t} + \lambda_u^* A_R^u)\right]}{|C_7^s|^2} \,. \tag{12}$$

The definitions of the quantities $A^{(1)K^*}$, $A^{(1)t}$, A^u and L_R^u can be seen in [3]. Their default values are summarized in Table 1, where we have also specified the theoretical errors in the more sensitive of these parameter L_R^u. The quantity $1 + \Delta R^0$ is obtained from Eq. (12) in the limit $L_R^u = 0$.

The isospin breaking ratio is given by

$$\Delta(\rho\gamma) = \frac{\Gamma^{\pm}(B \to \rho\gamma)}{2\ \Gamma^0(B \to \rho\gamma)} - 1 \tag{13}$$

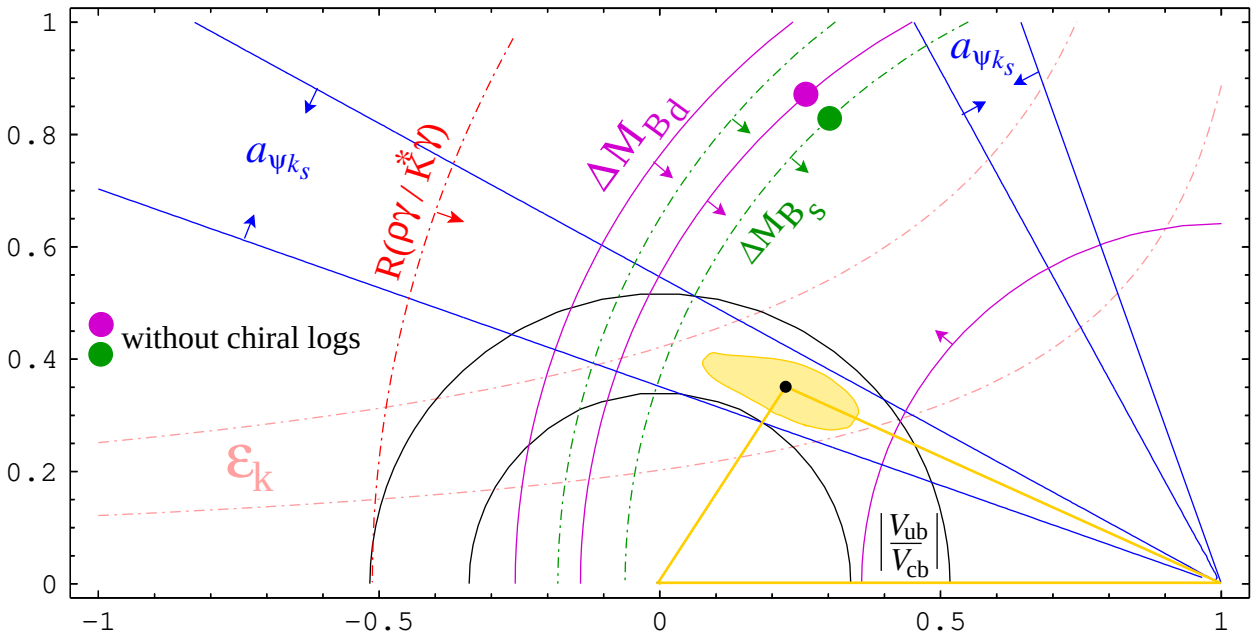

Figure 1: *Unitary triangle fit in the SM and the resulting 95% C.L. contour in the* $\bar{\rho}$ - $\bar{\eta}$ *plane. The impact of the* $R(\rho\gamma/K^*\gamma) < 0.047$ *constraint is also shown.*

$$= \left|\frac{C_7^d + \lambda_u L_R^u}{C_7^d}\right|^2 \left(1 - \frac{2\mathrm{Re}\, C_7^d (A_R^{(1)t} + \lambda_u^* A_R^u)}{|C_7^d|^2}\right) + \frac{2\ \mathrm{Re}\left[(C_7^d + \lambda_u L_R^u)(A_R^{(1)t} + \lambda_u^* A_R^u)\right]}{|C_7^d|^2} - 1\ , \tag{14}$$

and the CP asymmetry in the charged modes is

$$A_{CP}^{\pm}(\rho\gamma) = \frac{\mathcal{B}(B^- \to \rho^-\gamma) - \mathcal{B}(B^+ \to \rho^+\gamma)}{\mathcal{B}(B^- \to \rho^-\gamma) + \mathcal{B}(B^+ \to \rho^+\gamma)} \tag{15}$$

$$= -\frac{2\mathrm{Im}\left[(C_7^d + \lambda_u L_R^u)(A_I^{(1)t} + \lambda_u^* A_I^u)\right]}{|C_7^d + \lambda_u L_R^u|^2}\ . \tag{16}$$

The CP asymmetry in the neutral modes

$$A_{CP}^0(\rho\gamma) = \frac{\mathcal{B}(B^0 \to \rho^0\gamma) - \mathcal{B}(\bar{B}^0 \to \rho^0\gamma)}{\mathcal{B}(B^0 \to \rho^0\gamma) + \mathcal{B}(\bar{B}^0 \to \rho^0\gamma)} \tag{17}$$

is obtained from Eq. (16) in the limit $L_R^u = 0$.

Note, that as in the EMFV model there are additional contributions to the effective Wilson coefficients C_7, entering through the mass insertion parameters δ_{13}^u (for the $b \to d\gamma$ case) and δ_{23}^u (for the $b \to s\gamma$ case), which are in general different, we have introduced two different magnetic moment WC's for the d and s sectors. For $C_7^d = C_7^s = C_7^{\mathrm{SM}}$ we reproduce the formulae presented in Ref. [3] with the only exception of $\Delta R(\rho\gamma)$; in this case, the factor

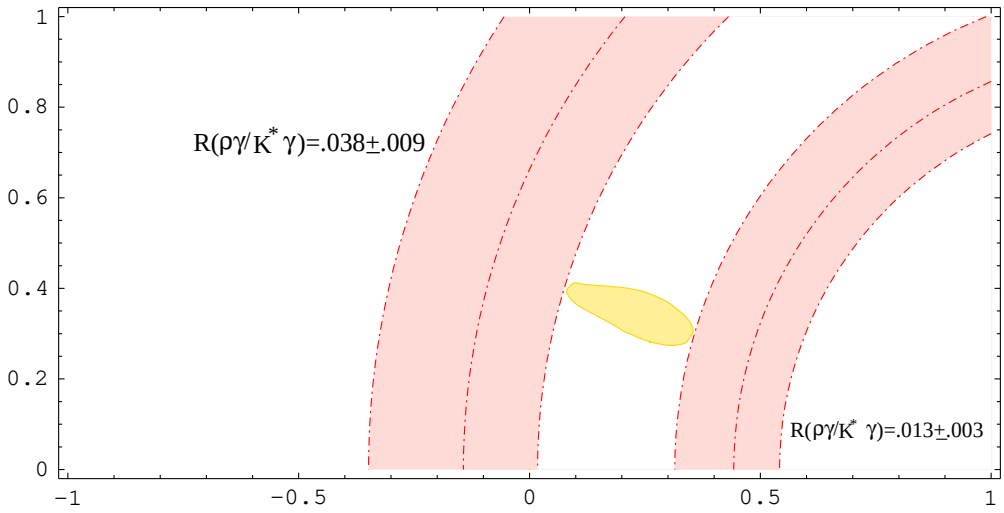

Figure 2: *Extremal values of $R(\rho\gamma/K^*\gamma)$ that are compatible with the SM unitarity triangle analysis.*

in the parentheses in the first line of Eq. (12) is missing in Ref. [3]. This, however, has only a small numerical effect, as can be judged from the values $\Delta R^{\pm} = 0.055 \pm 0.130$ and $\Delta R^0 = 0.015 \pm 0.110$ that we have obtained here and which are in quite good agreement with the corresponding values given in Ref. [3].

3 Impact on the unitarity triangle

In this section, we present an updated analysis of the constraints in the $(\bar{\rho}, \bar{\eta})$ plane from the unitarity of the CKM matrix, including the measurements of the CP asymmetry $a_{\psi K_s}$ in the decays $B^0/\overline{B^0} \to J/\psi K_s$ (and related modes), and show the impact of the upper limit $R(\rho\gamma/K^*\gamma) \leq 0.047$ [1].

The SM expressions for ϵ_K (CP-violating parameter in K decays), ΔM_{B_d} (B^0_d-$\bar{B}^0_d$ mass difference), ΔM_{B_s} (B^0_s-$\bar{B}^0_s$ mass difference) and $a_{\psi K_s}$ are fairly standard and can be found, for instance, in Ref. [17], where also references to the various theoretical input parameters which have not changed since then can be found. Note that for the hadronic parameters $f_{B_d}\sqrt{\hat{B}_{B_d}}$ and ξ_s, we use the recent lattice estimates [18] which into account uncertainties induced by the so-called chiral logarithms [19]. These errors are highly asymmetric and, once taken into account, reduce sizeably the impact of the $\Delta M_{B_s}/\Delta M_{B_d}$ lower bound on the unitarity triangle analysis. The experimental inputs for the quantities λ and ϵ_K are taken from the Particle Data Group [20]. The measurement of the CP asymmetry $a_{\psi K_s}$ in the decays $B^0/\overline{B^0} \to J/\psi K_s$ (and related modes) is now dominated by the BABAR [21] and BELLE [22] collaborations; taking into account the earlier measurements yield the current world average $a_{\psi K_s} = 0.734 \pm 0.054$ [23]. The indicated value of the mass difference $\Delta M_{B_d} = 0.503 \pm 0.006$ ps^{-1} is the current world average [24] and the 95% C.L. lower bound $\Delta M_{B_s} \geq 14.4$ ps^{-1} has been recently updated this summer [25]. The values of the theoretical

parameters and experimental measurements that we use are summarized in Table 1.

The SM fit of the unitarity triangle is presented in Fig. 1, where we show explicitly what happens to the allowed regions once the errors associated with the chiral logs are taken into account. The 95% C.L. contour is drawn taking into account chiral logarithm uncertainties. The fitted values for the Wolfenstein parameters, the angles α and β, ΔM_{B_s} and the CKM ratio $|V_{tb}/V_{ub}|$ are given below where we also show the resulting values that we obtain without including the chiral logarithms uncertainties:

	χ-logs	no χ-logs
$\bar{\rho}$	0.22 ± 0.07	0.25 ± 0.07
$\bar{\eta}$	0.34 ± 0.04	0.34 ± 0.04
α	$(98 \pm 10)^{\circ}$	$(101 \pm 10)^{\circ}$
β	$(24.2 \pm 1.8)^{\circ}$	$(25.0 \pm 1.9)^{\circ}$
γ	$(60 \pm 10)^{0}$	$(56 \pm 10)^{\circ}$
ΔM_{B_s}	$(19.6^{+4.4}_{-1.3})$ ps^{-1}	$(21.0^{+4.8}_{-1.4})$ ps^{-1}
$\left\|\frac{V_{td}}{V_{ub}}\right\|$	1.75 ± 0.15	1.61 ± 0.14

The main effect of the chiral logs is that they decrease the central value of $\bar{\rho}$ by about half a sigma with $\bar{\eta}$ remaining practically unchanged. The largest impact of this shift is in the increased value of the CKM matrix element ratio $\left|\frac{V_{td}}{V_{ub}}\right|$, whose central value moves up by about 1 sigma.

As the bound from the current upper limit on $R(\rho\gamma/K^*\gamma)$ is not yet competitive to the ones from either the measurement of ΔM_{B_d}, or the current bound on ΔM_{B_s}, we use the allowed $\bar{\rho} - \bar{\eta}$ region in order to work out the SM predictions for the observables in the radiative B-decays described above. Taking into account these errors and the uncertainties on the theoretical parameters presented in Table 1, we find the following SM expectations for the radiative decays:

$$R^{\pm}(\rho\gamma/K^*\gamma) = 0.023 \pm 0.012 \,, \tag{18}$$

$$R^{0}(\rho\gamma/K^*\gamma) = 0.011 \pm 0.006 \,, \tag{19}$$

$$\Delta(\rho\gamma) = 0.04^{+0.14}_{-0.07} \,, \tag{20}$$

$$A_{CP}^{\pm}(\rho\gamma) = 0.10^{+0.03}_{-0.02} \,, \tag{21}$$

$$A_{CP}^{0}(\rho\gamma) = 0.06 \pm 0.02 \,. \tag{22}$$

It is interesting to work out the extremal values of $R(\rho\gamma/K^*\gamma)$ compatible with the SM UT-analysis. This is geometrically shown in Fig. 2 where we draw the bands corresponding to the values 0.038 ± 0.009 and 0.013 ± 0.003 (the errors are essentially driven by the uncertainty on ζ). The meaning of this figure is as follows: any measurement of $R(\rho\gamma/K^*\gamma)$, whose central value lies in the range $(0.013, 0.038)$ would be compatible with the SM, irrespective of the size of the experimental error. The error induced by the imprecise determination of the isospin breaking parameter ζ limits currently the possibility of having a very sharp impact from $R(\rho\gamma/K^*\gamma)$ on the UT analysis.

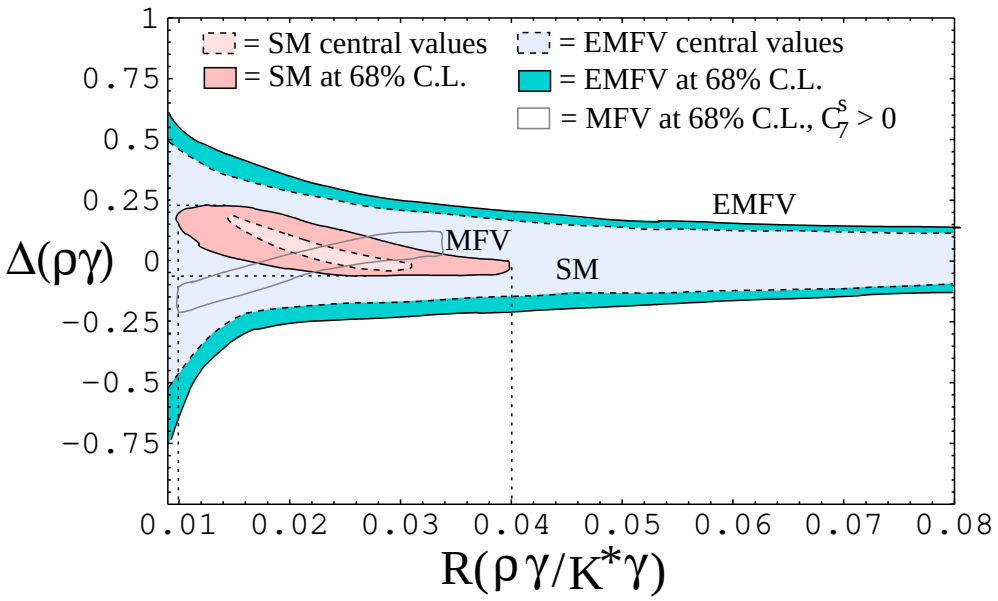

Figure 3: *Correlation between $R(\rho\gamma/K^*\gamma)$ and $\Delta(\rho\gamma)$ in the SM and in MFV and EMFV models. The light-shaded regions are obtained varying $\bar{\rho}$, $\bar{\eta}$, the supersymmetric parameters (for the MFV and EMFV models) and using the central values of all the hadronic quantities. The darker regions show the effect of $\pm 1\sigma$ variation of the hadronic parameters.*

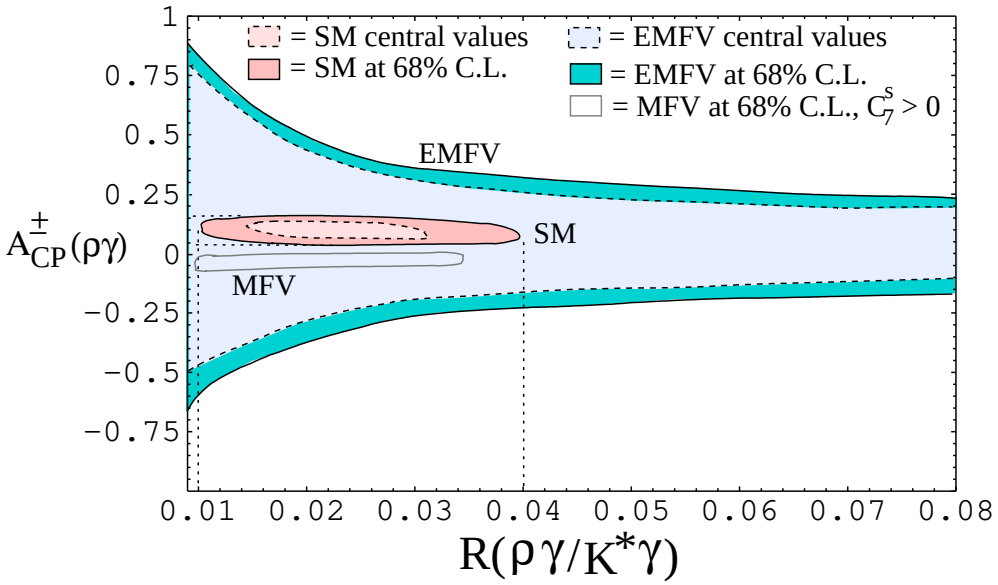

Figure 4: *Correlation between $R(\rho\gamma/K^*\gamma)$ and $A_{CP}^{\pm}(\rho\gamma)$. See the caption in Fig. 3 for further details.*

4 Analysis in supersymmetry

We focus on two variants of the MSSM called in the literature as MFV [12] and Extended-MFV [13] models. In MFV models all the flavor changing sources, other than the CKM matrix, are neglected and the remaining parameters (that are assumed to be real) are the common mass of the heavy squarks other than the lightest stop ($M_{\tilde{q}}$), the mass of the lightest stop ($M_{\tilde{t}}$), the stop mixing angle ($\theta_{\tilde{t}}$), the ratio of the vacuum expectation values of the two Higgs bosons ($\tan\beta_S$), the two parameters of the chargino mass matrix (μ and M_2) and the charged Higgs mass ($M_{H^\pm}$). In this class of models there are essentially no additional contributions (on top of the SM ones) to $a_{\psi K_S}$ and $\Delta M_{B_s}/\Delta M_{B_d}$, while the impact on ϵ_K, ΔM_{B_d} and ΔM_{B_s} is described by a single parameter f, whose value depends on the parameters of the supersymmetric models [17].

In EMFV models, there is an additional parameter

$$\delta_{\tilde{u}_L\tilde{t}} = \frac{M^2_{\tilde{u}_L\tilde{t}}}{M_{\tilde{t}}M_{\tilde{q}}}\frac{V_{td}}{|V_{td}|} \ . \tag{23}$$

With the inclusion of this new parameter, the description of the UT-related observables needs one more complex parameter, $g = g_R + ig_I$ [13]. A signature of these models is the presence of a new phase in the $B^0_d - \bar{B}^0_d$ mixing amplitude. Using the parametrization $M^d_{12} = r^2_d e^{2i\theta_d} M^{\rm SM}_{12}$, we get $r^2_d = |1 + f + g|$ and $\theta_d = 1/2\arg(1 + f + g)$. This implies supersymmetric contributions to the CP asymmetry $a_{\psi K_s}$, which we quantify below.

We analyze the phenomenology of the MFV and EMFV models by means of scatter plots over the supersymmetric parameter space. In the MFV case, we scan over the following ranges ($M_{\tilde{q}}$ is set to 1 TeV, likewise $M_{\tilde{g}}$ is $O(1$ TeV)):

$$M_{\tilde{t}} = [0.1 \div 1] \text{ TeV} \ , \tag{24}$$
$$\theta_{\tilde{t}} = [-\pi \div \pi] \ , \tag{25}$$
$$\tan\beta_S = [3 \div 50] \ , \tag{26}$$
$$M_2 = [0.1 \div 1] \text{ TeV} \ , \tag{27}$$
$$M_{H^\pm} = [0.1 \div 1] \text{ TeV} \ . \tag{28}$$

In the EMFV case, we limit the range of the stop mixing angle to $\theta_{\tilde{t}} = [-0.3 \div 0.3]$ (see discussion in Ref. [13]) and add the scan over $|\delta_{\tilde{u}_L\tilde{t}}| = [0 \div 1]$ and $\arg\delta_{\tilde{u}_L\tilde{t}} = [-\pi \div \pi]$. We scan also over $\bar{\rho}$ and $\bar{\eta}$ and require that each point satisfies the bounds that come from direct searches, from the $B \to X_s\gamma$ branching ratio, and from the UT related observables summarized in Table 1. The surviving regions are presented in Figs. 3-5. In each figure, the light shaded regions are obtained using the central values of the input parameters given in Table 1 while the dark shaded ones result from the inclusion of their one sigma errors. Note that in the two figures showing the correlations between $A^\pm_{\rm CP}(\rho\gamma)$ and $R(\rho\gamma/K^*\gamma)$, and $A^0_{\rm CP}(\rho\gamma)$ and $R(\rho\gamma/K^*\gamma)$, respectively, the CP asymmetries tend to increase as expected in the limit of small branching ratios. In the MFV case, there are two distinct regions that correspond to the negative (SM-like) and positive C^s_7 cases. For $C^s_7 < 0$, the allowed regions in MFV almost coincide with the SM ones and we do not draw them. For $C^s_7 > 0$, the allowed

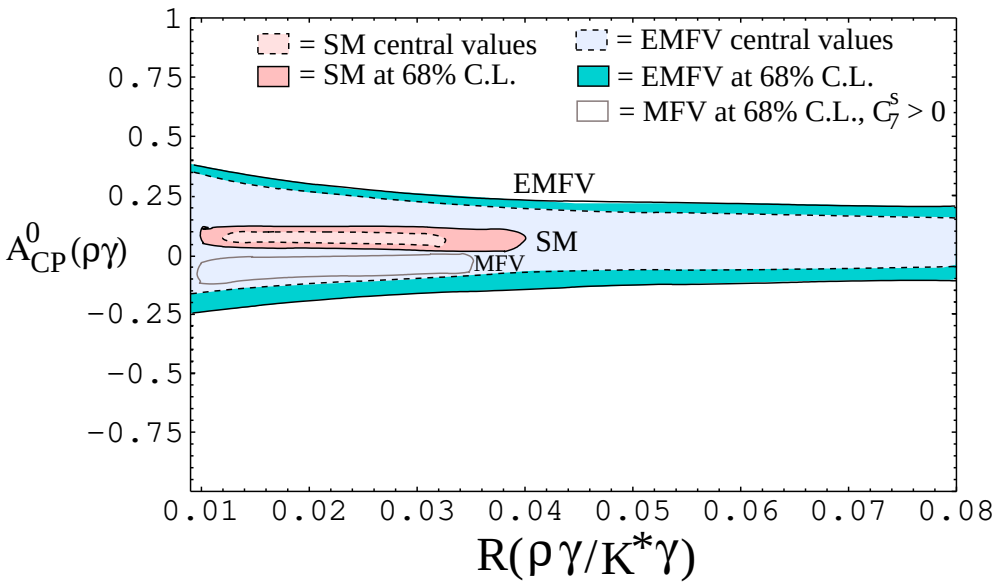

Figure 5: *Correlation between $R(\rho\gamma/K^*\gamma)$ and $A_{CP}^0(\rho\gamma)$. See the caption in Fig. 3 for further details.*

regions are different and, in general, a change of sign of both the CP-asymmetries (compared to the SM) is expected. We note that the latter scenario needs very large SUSY contributions to C_7^s, arising from the chargino-stop diagrams, and for fixed values of $\tan\beta_S$ it is possible to set an upper limit on the mass of the lightest stop squark. In Fig. 6, we show the points that survive the $B \to X_s\gamma$ constraint with a positive C_7^s in the MFV scenario. We have also imposed the additional constraint coming from the upper limit $\mathcal{B}(B_s \to \mu^+\mu^-) < 2.6 \times 10^{-6}$ at 90% C.L. [27], and find that the allowed region is essentially unaffected. Note that in the $C_7^s > 0$ scenario the mass of the lightest stop has an upper bound of 500 GeV for $\tan\beta_S < 50$.

What concerns the allowed values of the phase θ_d, comparing the SM allowed range from the UT fit $\sin 2\beta = 0.76 \pm 0.06$, implying $\beta = 25^\circ \pm 3^\circ$, with the current experimental value $a_{\psi K_s} = 0.734 \pm 0.054$, yields $\theta_d \in (-5^\circ, 8^\circ)$. The other solution for $a_{\psi K_s}$ shown in Fig. 1 yields $\theta_d \in (33^\circ, 46^\circ)$. The additional contributions in M_{12}^d impact on the dilepton charge asymmetry [26]

$$A_{\ell\ell} \equiv \frac{\ell^{++} - \ell^{--}}{\ell^{++} + \ell^{--}} = \left(\frac{\Delta\Gamma_d}{\Delta M_d}\right)_{\rm SM} \frac{r_d^2 \sin 2\theta_d}{1 + 2r_d^2 \cos 2\theta_d + r_d^4} \,,$$

where $\ell^{++}(\ell^{--})$ are the numbers of $\ell^+\ell^+(\ell^-\ell^-)$ observed in the decay of a $B\bar{B}$ pair, and $\Delta\Gamma_d$ is the difference in the decay widhts of the two mass eigenstate. We have computed for each point the value of the dilepton asymmetry $A_{\ell\ell}$ and found that the allowed range in the EMFV model is $A_{\ell\ell} \in [-0.1, 0.7] \times 10^{-2}$. This expectation has to be compared with the current experimental bound, $A_{\ell\ell}^{\rm exp} = (0.46 \pm 1.18 \pm 1.43) \times 10^{-2}$ [28]. We see that the experimental precision has to be improved by one order of magnitude in order to test the EMFV models. Note that $(\Delta\Gamma_d/\Delta M_d)_{\rm SM} = (1.3 \pm 0.2) \times 10^{-2}$, yielding typically $A_{\ell\ell} = O(10^{-3})$ in the SM.

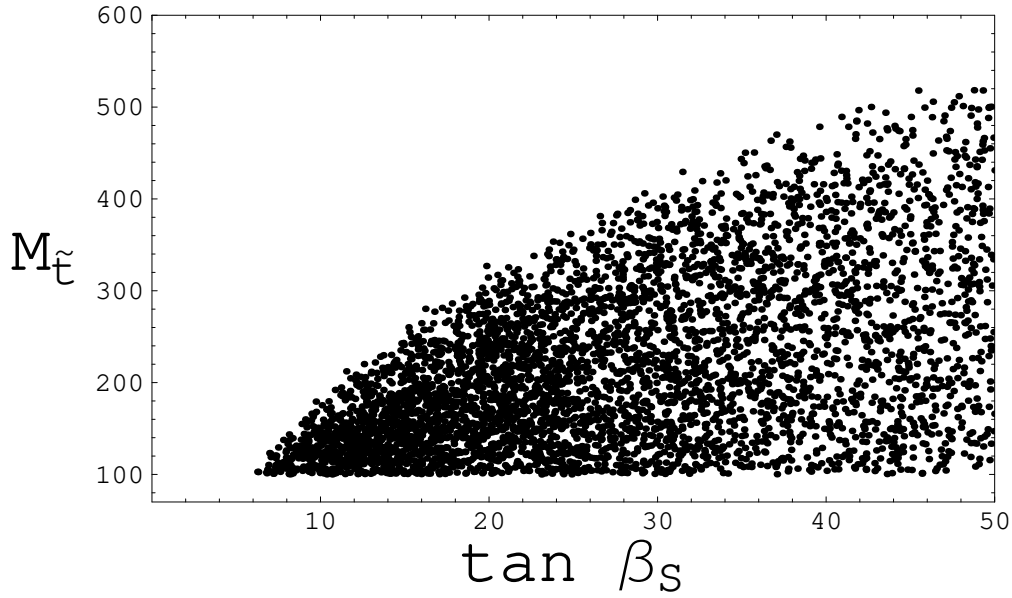

Figure 6: *Correlation between* $\tan\beta_S$ *and* $M_{\tilde{t}}$ *(in GeV) in the MFV-SUSY model for the* $C_7^s > 0$ *scenario.*

5 Summary

We have presented here an analysis of the ratio $R(\rho\gamma/K^*\gamma)$, involving the decays $B \to \rho\gamma$ and $B \to K^*\gamma$, the isospin-violating asymmetry in $B \to \rho\gamma$ decays $\Delta(\rho\gamma)$, and direct CP asymmetries $A_{\rm CP}^{\pm}(\rho\gamma)$ and $A_{\rm CP}^{0}(\rho\gamma)$ in the charged and neutral B-meson decays in the SM and two variants of supersymmetric theories. They illustrate the current and impending interest in the radiative decays $B \to \rho\gamma$, which will provide powerful constraints on the CKM parameters and allow to search for physics beyond-the-SM.

Acknowledgments

We would like to thank David London and Alexander Parkhomenko for helpful correspondence and discussions. E.L. thanks Frank Krüger and Athanasios Dedes for useful discussions, and acknowledges financial support from the Alexander von Humboldt foundation.

References

[1] B. Aubert *et al* [BABAR Collaboration], BABAR-CONF-02/024, SLAC-PUB-9319, hep-ex/0207073.

[2] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **88**, 101805 (2002).

[3] A. Ali and A. Y. Parkhomenko, Eur. Phys. J. C **23**, 89 (2002).

[4] A. Ali, V. M. Braun and H. Simma, Z. Phys. C **63**, 437 (1994).

[5] A. Ali and V. M. Braun, Phys. Lett. B **359**, 223 (1995).

[6] A. Khodjamirian, G. Stoll and D. Wyler, Phys. Lett. B **358**, 129 (1995).

[7] B. Grinstein and D. Pirjol, Phys. Rev. D **62**, 093002 (2000).

[8] M. Beyer, D. Melikhov, N. Nikitin and B. Stech, Phys. Rev. D **64**, 094006 (2001).

[9] M. Beneke, G. Buchalla, M. Neubert and C. T. Sachrajda, Phys. Rev. Lett. **83**, 1914 (1999).

[10] S. W. Bosch and G. Buchalla, Nucl. Phys. B **621**, 459 (2002).

[11] M. Beneke, T. Feldmann and D. Seidel, Nucl. Phys. B **612**, 25 (2001).

[12] M. Ciuchini, G. Degrassi, P. Gambino and G. F. Giudice, Nucl. Phys. B **534**, 3 (1998).

[13] A. Ali and E. Lunghi, Eur. Phys. J. C **21**, 683 (2001).

[14] P. Ball and V. Braun, Phys. Rev. D **58** (1998) 094016.

[15] S. Narison, Phys. Lett. B **327** (1994) 354.

[16] D. Melikhov and B. Stech, Phys. Rev. D **62** (2000) 014006.

[17] A. Ali and D. London, Eur. Phys. J. C **9**, 687 (1999); Phys. Rept. **320**, 79 (1999).

[18] See, for example, L. Lellouch, plenary talk at the 31st. International Conference on High Energy Physics, July 24 - 31, 2002, Amsterdam, The Netherlands.

[19] A. S. Kronfeld and S. M. Ryan, hep-ph/0206058.

[20] K. Hagiwara *et al.* (Particle Data Group Collaboration), Phys. Rev. D **66** (2002) 010001. [21]

[21] B. Aubert *et al.* [BABAR Collaboration], hep-ex/0207042.

[22] K. Abe *et al.* [BELLE Collaboration], hep-ex/0208025.

[23] Y. Nir, hep-ph/0208080.

[24] A. Stocchi, plenary talk at the 31st. International Conference on High Energy Physics, July 24-31, 2002, Amsterdam, The netherlands.

[25] S. Willocq, hep-ex/0208008.

[26] L. Randall and S.-f. Su, Nucl. Phys. B **540**, 37 (1999).

[27] F. Abe *et al.* (CDF Collaboration), Phys. Rev. D **57**, 3811 (1998).

[28] S. Sekula (BABAR Collaboration), talk presented at the 2nd. Int. Workshop on B Physics and CP Violation, National Taiwan University, Taipei, June 7-9, 2002.